Automated Design Reference Mission Generation for THEIA

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Abstract

We present and refine an algorithm for the automated generation of Design Reference Missions (DRMs) for planet finding space-borne instruments. Unlike previous DRM tools, our algorithm automatically generates an initial target list, and auto-schedules visits and re-visits to these targets based on pre-set parameters which are translatable to mission rules. In addition to previously demonstrated completeness and return visit optimizations, we also incorporate a more realistic model of spacecraft orbital transfers (for missions incorporating occulters), an advanced integration time calculation based on desired false alarm probabilities, missed detection rates and the specific instruments' characteristics, and the possibility of multiple planets in some extra-solar systems. Finally, we allow for the incorporation of multiple free parameters including the frequency of occurrence of Earth-like planets. We apply the algorithm to the THEIA mission concept and present average mission results compared with other architectures.

Exo-Planet Types

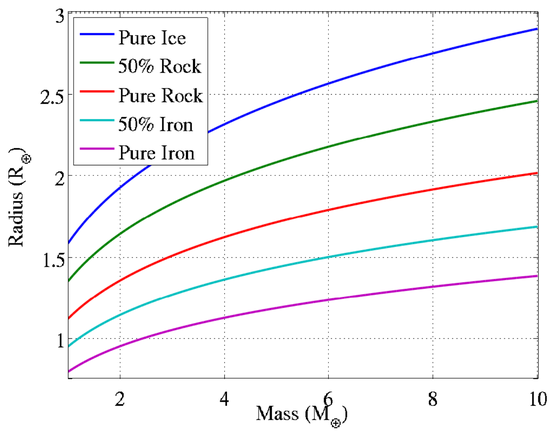

Figure: Rocky Planet Densities. [Fortney et al., 2007]

- Earth-twins: Exact copies of the Earth.
- (Super) Earths: 1 - 10 $M_\oplus$, composed of mixtures of iron and rock or rock and ice.
- Neptunes (Ice Giants): 10 - 100 $M_\oplus$, with at least 50% of the mass concentrated in the core.
- Giants: 100-3000 $M_\oplus$, with less than 50% of the mass in the core.

For each simulation, a random sample of planets is generated based on the specified type, orbital element and frequency ranges.

Target Stars

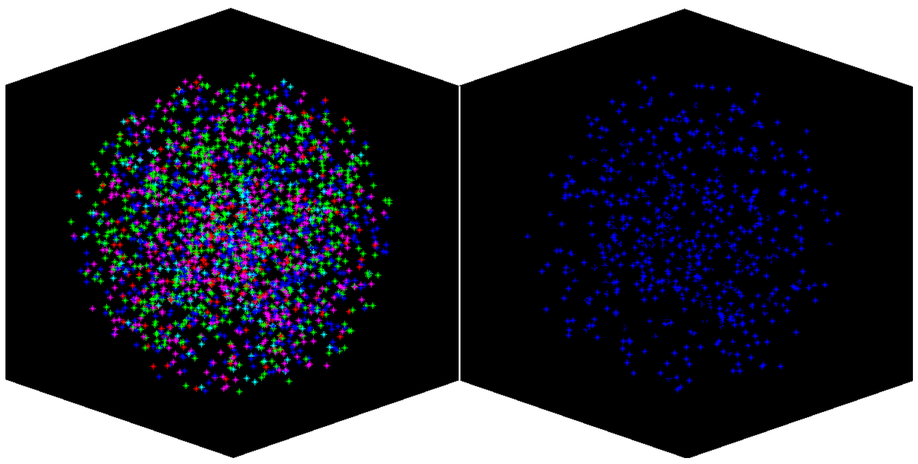

Figure: (a) All 2350 stars within 30pc of the Earth. (b)The 558 stars that are good candidates for having Earth-like planets.

Target lists are generated based on the instruments specifications (inner working angle and achievable contrast) as well as the actual stars available.

Completeness [Brown, 2005]

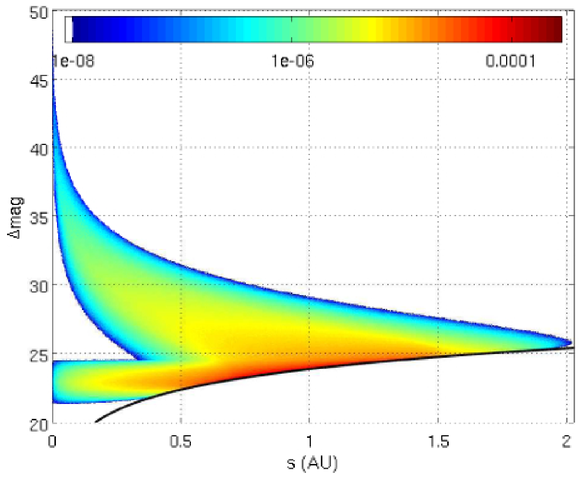

Figure: Probability density function of observable 'Earth-like' planets ($a \in [0.7, 1.5]$, $e \in [0, 0.35]$, $p = 0.33$, $R = R_\oplus$). The color scale represents the probability of detecting a planet at a given inner working angle (IWA) and Δmag (difference in brightness between planet and star) during one observation, assuming sufficient integration time.

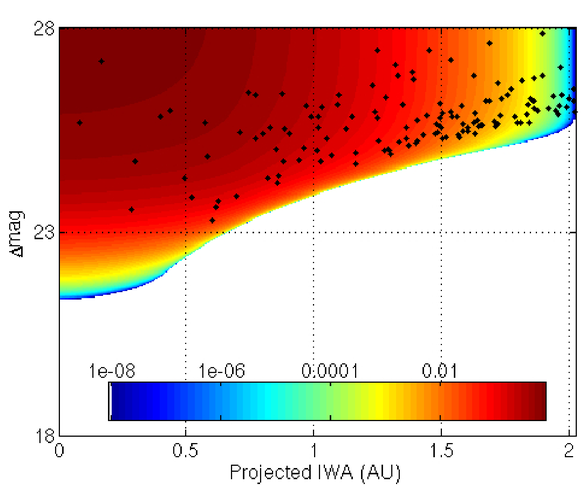

Figure: Candidate stars plotted over the single visit completeness for 'Earth-like' planets (the cumulative distribution function of the plot to the left). The color scale represents the probability of detecting a planet during one observation, for an instrument with a given IWA and limiting Δmag.

References

Brown, R. A. (2005).
Single-visit photometric and obscurational completeness.
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Fortney, J. J., Marley, M. S., and Barnes, J. W. (2007).
Planetary radii across five order of magnitude in mass and stellar insolation: application to transits.
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Linear and bayesian planet detection algorithms for the terrestrial planet finder.
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Design reference mission construction for planet finders.
In J. M. Oschmann, J., de Graauw, M. W. M., and MacEwen, H. A., editors, *Space Telescopes and Instrumentation 2008: Optical, Infrared, and Millimeter*, volume 7010 of *Proc. SPIE*. SPIE.

Time Calculations

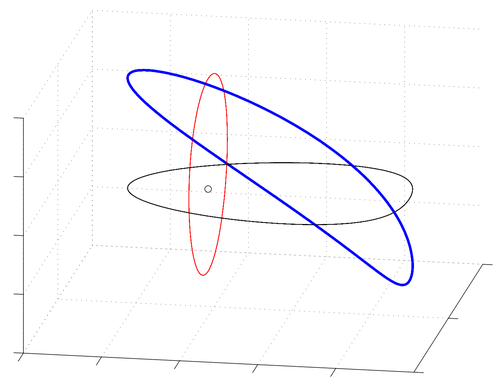


Figure: The satellite's L2 halo orbit (blue) is simulated and used to optimize transfer times for systems with occulters. Projections of the orbit are shown in black and red.

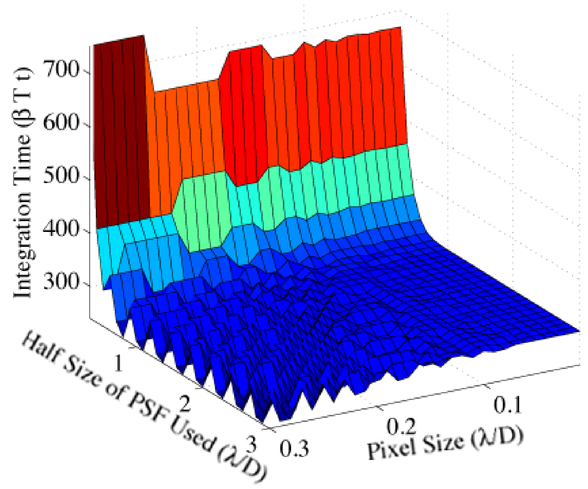
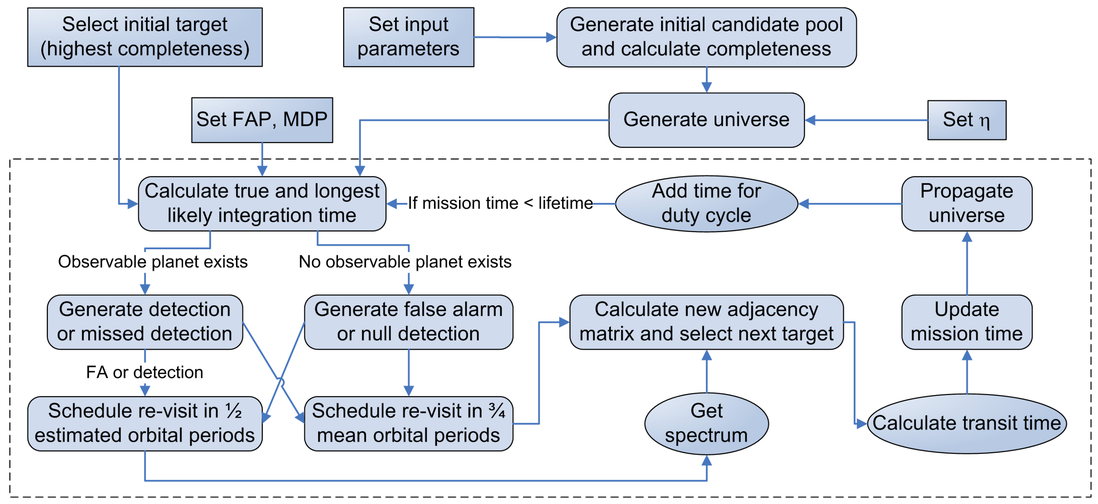
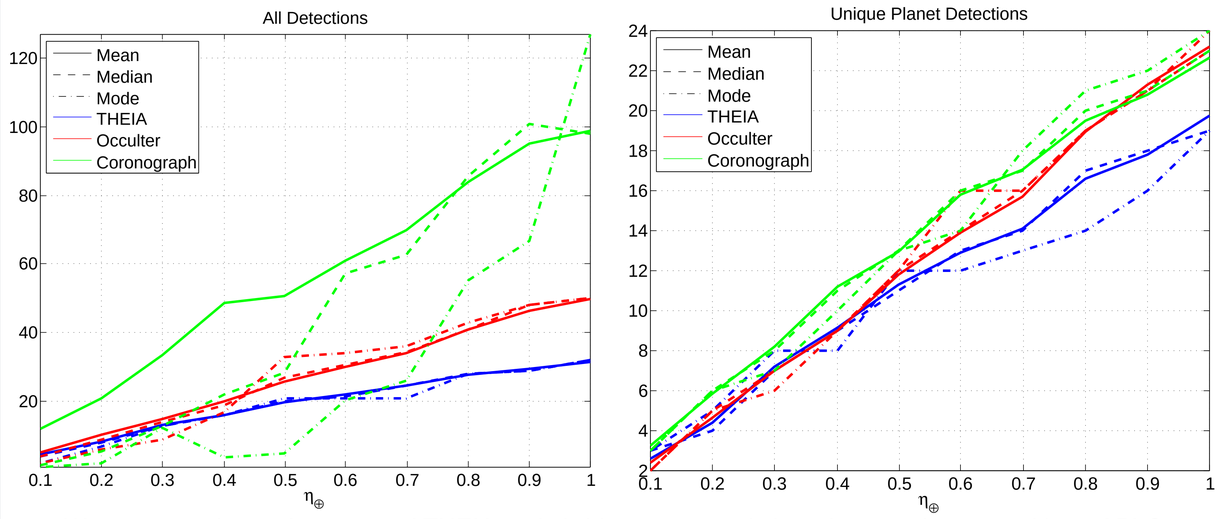


Figure: The optical system's PSF and other specifications are used to calculate detection and characterization time, accounting for desired missed detection rates and false alarm probabilities. [Kasdin and Braems, 2006]

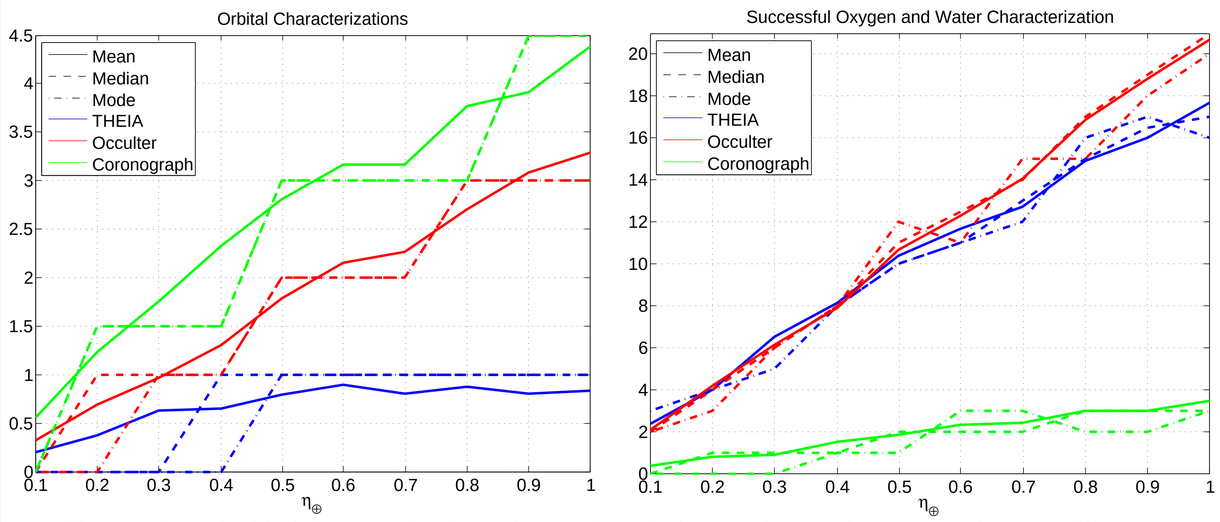
Simulation Algorithm [Savransky and Kasdin, 2008]



Results



We compare the performance of THEIA - a hybrid system consisting of a 4m telescope with an APLC and a 40m occulter operating at two separation distances, a 4m telescope with a 52.8m occulter (both with an IWA of 75 mas), and a 4m internal coronograph with an IWA of 3 λ/D. The simulations are of 5 year missions in a universe of single-planet Earth-twin systems. The free parameter ($\eta_\oplus$) is the frequency of Earth-like planets in the universe (i.e., the fraction of target stars that have a planet).



The number of orbital characterizations (the number of planets observed 4 or more times at different orbital locations) and the number of successful oxygen and water characterizations (S/N = 11 at wavelengths up to 1 μm).

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